THE GRADUAL SURGICAL OCCLUSION OF LARGE ARTERIES: ITS RELATIVE ADVANTAGES, TOGETHER WITH AN EXPERIMENTAL INQUIRY AS TO ITS FEASIBILITY.[1]

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MURPHY'S demonstration of the possibility of restoring the lumen of resected arteries by circular arteriorrhaphy, Crile's and Keen's reports of successful temporary closure of large arteries, Matas's apparently radical cure of aneurism by suture and infolding of the sac, and the work of other investigators and clinicians in our own and other countries have called the attention of the profession to the fact that the chapter on the surgical technique in relation to the larger blood-vessels is not closed, and form the reasonable basis of a hope that much more will yet be accomplished in that field of surgery.

The dangerous results which attend the ligation of the largest arteries call for improvement, if possible, in our methods. At least, such unfortunate sequelæ of ligation as are due to the suddenness with which that procedure is now practised would seem to be within the range of prevention. While it is true that in a large proportion of individuals abrupt surgical closure of large arteries is unattended with alarming symptoms, yet in other patients the same procedure causes, immediately or remotely, grave dangers. This is especially true if the heart of the patient is weak, or his blood-vessels are wanting in the usual elasticity, or if for any reason his vital force is impaired. In case of ligation of the innominate or common carotids, experience teaches us that we may fear convulsions or paralysis, mental disorder or immediately fatal cardiac palpitation and dyspnœa; in the case of the abdominal aorta, paralysis or mortification of the lower extremities, prolonged and severe pain, extreme shock and dangerous or fatal effects upon the heart. In case of ligation of other large arteries, but those less closely associated with vital organs and processes—the iliac, femoral, subclavian—gangrene may be feared. Failure of the establishment of the collateral circulation will also best account for some of the deaths from cerebral disease following ligation of the carotids. These effects are in large part, if not entirely, due to the suddenness of the arterial closure, certain areas being abruptly deprived of their accustomed blood supply, or to the damming back of the blood, resulting in an excessive amount being thrown upon the heart, the brain, and probably the lungs. Keen's case of ligation of the abdominal aorta very vividly portrays some of the dangers and results of abrupt closure. At the moment the ligature was applied, the pulse rose from 90 to 130, and the patient's head, face, and neck became deeply congested and almost livid.

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Pathology can teach us valuable lessons in this regard. A limb suddenly deprived of its arterial blood supply is more apt to become gangrenous than when the deprivation is gradual. Furthermore, the complete closure of large arteries by the very gradually increasing pressure of growing tumors is unaccompanied by symptoms due to such occlusion, the collateral circulation being slowly and completely perfected and without reflux congestive disturbances. The more nearly the surgeon approximates the method of nature in this respect the more successful will be his efforts to accomplish his purpose. It will certainly be a decided step ahead, if, in addition to securing closure without the immediately dangerous effects upon the vital organs due to the abruptness of our present ligations, a method can be discovered which will better facilitate the establishment of the collateral circulation. Furthermore, if the method will determine the impossibility of accomplishing that, at a time when the caliber of the vessel can be safely restored and the method abandoned without material risk, the advance will be more marked.

It is a question yet to be clinically decided whether the collateral circulation in case of surgical closure would be more surely established if the arterial occlusion were gradually accomplished than it is by the present abrupt method. But the experience that pathology presents that arterial closure by tumor growth does not cause gangrene, and that even in diffuse arteriosclerosis the degenerative process may not involve all the arterioles, and at any rate in these smaller vessels may exist in less advanced form, would tend to show that failure of the collateral circulation in our operative work was in large part due to the suddenness of the method. Moreover, it seems reasonable that if the vitality of distal parts can be merely sustained by partial arterial patency while even arterioles with lessened elasticity have, under prolonged increased intravascular pressure, had an opportunity to enlarge, that they will, in most cases, ultimately do so to such a degree as to permit the still further, even the complete, closure of the artery.

My first experiment undertaken to test the practicability of gradual occlusion consisted in an attempt to apply a clamp to the abdominal aorta of a dog. The result made me feel that some other method by which the pressure around the artery could be more delicately adjusted and which would permit an easier and safer removal of the apparatus was highly desirable. Subsequent to this, Keen undertook to prove the feasibility of direct temporary complete compression of the abdominal aorta by means of a clamp, and, for this purpose, he operated upon a number of dogs, and showed that it was possible to do so in that animal with comparative safety. It does not appear, however, from the reading of the report of his experiments (*American Journal of Medical Sciences*, September, 1900) that the idea of gradual occlusion of that or other arteries was contemplated by him. The closest approach to anything in the line of gradual surgical occlusion of blood-vessels of which I can learn was undertaken by Milton in 1890 (*Lancet*, 1891, Vol. i, p. 85), when, in considering operative procedures in relation to the cure of aneurism of the abdominal aorta, he devised a plan to apply direct pressure to the vessel by means of a rubber tube passed through the lumbar muscles and around the spine and aorta. His idea was not, however, put to a practical test. His plan was to " compress the aorta against the vertebral column by traction on the two ends of the drainage tube. The amount of pressure to be applied and the period of its application were to be regulated by the effect produced on the patient." It does not appear, however, that gradual progressive occlusion was distinctly conceived or intended, or that, as a general surgical principle, it was clearly recognized or suggested as applicable to other vessels.

From the numerous different procedures proposed and instruments invented for the purpose of effecting direct or indirect, partial or complete temporary compression of large arteries for the cure of aneurism, notwithstanding my inability with considerable searching to discern its distinct conception, it is hardly likely that the closely related principle of gradual occlusion was not apprehended. But whether this be true or not, there certainly remains room at this time for its clear and emphatic pronouncement and the suggestion, if possible, of such a feasible technique that it may be accorded general professional recognition.

In my subsequent experiments along this line I endeavored to test the practicability of gradual occlusion with an instrument operating upon the principle of the écraseur. This would permit, I thought, of a very delicate adjustment of the degree of constriction of the artery, it would not be easily displaced, and would be quite readily removable. The abdominal aorta of medium-sized female dogs was selected for these trials.

EXPERIMENT 2.—Arterial closure effected by means of largest size iron-dyed silk ligature passed around artery and through a slender, gauze-covered, German silver cylinder, with a circular, perforated disk the size of a dime attached transversely to the extremity to be placed in contact with the blood-vessel. The ligature was fixed at its outer extremity by means of a slender, cone-shaped, wooden plug pressed into the aperture of the constrictor, thus binding the ligature at any desired degree of tension upon the artery.

May 20, 9.30 A.M. Ligature applied to aorta about one inch above bifurcation, the size of the artery approximating closely to that of the carotid in man. Abdomen closed around the instrument and dog encased in plaster of Paris. Ligature then tightened until a pronounced effect was produced upon the femoral pulse and fixed at that point, after testing the working of the instrument and noting that the pulse could be perfectly controlled by relaxing or increasing the tension of the ligature.

2 P.M. No paralysis of the posterior extremities exists, although the hind legs are cooler than the front.

May 21, 9.30 A.M. Constrictor tightened so as to make a just perceptible femoral pulse. Dog apparently strong and not suffering.

2 P.M. Dog has struggled out of cast and the ligator subjected to great violence. Wound uncovered, and a knuckle of intestine protruding from abdominal cavity is cold and covered with dirt. Intestine cleansed and replaced with difficulty. Forcible femoral pulse noticed. The ligator firmly tightened so as to entirely abolish the femoral pulse.

10 P.M. No pulse yet perceptible. Ligator relaxed and quite a full pulse returns. Tightened to a point allowing a just perceptible pulse and fixed there. Thighs have remained warm.

May 22, 5 A.M. No femoral pulse.

11 A.M. No pulse has returned, although the thighs are quite warm. No paralysis exists. Abdomen opened. Intestines and omentum matted around ligator and adherent to the abdominal wall. Mass of inflammatory exudate around artery at the point of ligation. Ligature removed. Aorta ligated about one inch higher on account of severe hæmorrhage attending a different experiment at arterial closure. Abdomen sutured and dog allowed freedom. Continued in poor general condition, apparently weak and exhausted, refusing food and vomiting. No femoral pulse felt at any time, but thighs warm and not paralyzed.

Dog killed at 11 A.M., May 26, the sixth day from the original operation. The cause of the dog's failure was found to be necrosis of a knuckle of intestine. Mesentery adjacent to bowel also necrotic. Deeper parts of mesentery healthy, showing condition not the result of aortic ligation, but rather the result of traumatism and exposure incident to dog's struggles. The site of the application of the gradual ligator was carefully examined. A mere suggestion of thinning of the arterial wall was discernible, notwithstanding the extreme violence to which the constrictor had been subjected, and that only a heavy silk ligature was used. Its location could only be recognized on careful examination by slight ecchymosis of the adventitia and redness of the arterial tunics on longitudinal incision, together with a very slight, superficial roughening of the intima in three small areas. In this experiment the constrictor was applied to the artery for fifty hours, twenty-nine hours elapsing before the lumen of the vessel was occluded.

EXPERIMENT 3.—In this and the following trials, a cotton tape one-fourth of an inch wide was passed around the aorta and through a gauze-covered, sterling silver, hollow shaft of light weight, both ends of the tape being fastened to the axle of a small windlass fixed to the instrument at its outer extremity. The revolving of this tightened or relaxed the tape at the will of the operator, while the wheel could be fixed at any point by means of a hinged bar being pressed into small slots in the margin of the wheel. The shape of the extremity of the instrument to be placed adjacent to the artery was so formed as to permit a slight rolling outward of the margin of the tape in contact with the artery. The object of this was to avoid, if possible, traumatism of the arterial wall by the pulsation of the aorta against a tense tape margin.

Operation, June 3, 10 A.M. Tape applied loosely to the abdominal aorta about two and a half inches above bifurcation.

11 A.M. The tape tightened until there was a perceptible effect upon the femoral pulse, the working of the instrument having been previously tested, and it was noted that the pulse could be caused to disappear or return at will.

2 P.M. Tape tightened slightly.

11 P.M. Femoral pulse detected.

1 A.M. Dog alive. No paralysis noted at any time.

June 4, 8 A.M. Dog found dead, apparently from strangulation due to the inspiration of vomitus, the result of the fixed position of dog in cast.

Autopsy.—One-half or less of the caliber of the aorta was found to be occluded by the tape. Removal of latter required considerable force on account of its close adhesion to the artery. Ecchymosis of the arterial wall locally at the site of the ligator. Vitality of the arterial wall apparently good. Intima found lacerated superficially in short transverse lines at site of tape, as if from stretching upon its withdrawal. No other lesion was discernible. In this case the constrictor was applied so as to partially occlude the aorta for about fifteen hours.

EXPERIMENT 4.—September 4, 12 M. Applied tape constrictor about one inch above the bifurcation of the aorta, the tape being infiltrated with paraffin with a view of preventing its adhesion to the artery, thereby facilitating its removal. Instrument controlled perfectly the flow of blood through the artery. Before operation closed, the ligator was tightened so as to reduce about one-half the volume of blood passing through the aorta. After operation, when anæsthesia had passed off, there was no paralysis of the hind legs.

4 P.M. Tape slightly tightened so as to further reduce femoral pulse. Dog resting easily and in good condition.

9 P.M. Ligator still further tightened.

September 5, 8 A.M. Femoral pulse apparently stronger than at last examination. Tape tightened and pulse reduced. General condition good, not suffering; takes food voluntarily. Hind legs warm; no paralysis.

4 P.M. Constrictor tightened, so that the femoral pulse is just perceptible. A slight turn of the wheel entirely shuts off the pulse.

7 P.M. Femoral pulse not perceptible.

11 P.M. Femoral pulse absent. Constrictor tightened to the full extent. Artery, although not pulsating, less plainly felt thereafter. Legs warm.

September 6, 9 A.M. No femoral pulse. General condition very good. No paralysis. Tape loosened and femoral pulse felt rather feebly.

10.30 A.M. Dog examined under anæsthesia. Ligature had been applied forty-seven hours, during about thirty hours of which time the lumen of the vessel was partially occluded. Wound in excellent condition; no sepsis. Omentum and intestines matted to the abdominal wall and to each other around the instrument, the ligator being completely walled off from the peritoneal cavity. Pulsation felt in the abdominal aorta below tape. The instrument was removed and the tape withdrawn by traction on one end, no undue force being required. Arterial wall at site of tape constrictor is firm, thickened, and ecchymotic. Dog killed with chloroform and artery removed. Small recent clot found in artery at site of tape.

Microscopic examination was kindly made by Dr. C. W. Dodge, who reported all three coats of the artery at the site of the occlusion intact.

In this case much difficulty was met with in the removal of the instrument by reason of the close adhesion of its gauze envelope to the intestines. The tape, however, was readily removable.

EXPERIMENT 5.—Paraffined tape constrictor applied one inch above bifurcation, partly closing lumen of aorta; in place forty-four hours. Progressive constriction carried on at intervals during forty-three hours before closure effected. No paralysis. Instrument and gauze withdrawn with ease; tape required more, but not undue force. Dog killed fourteen hours after removal of tape.

In this experiment, gauze was arranged in spiral form loosely around ligator after the latter was in place. Application of cast after completion of operation caused marked change in angle of ligator with artery, together with a partial twist of its transverse axis. Rectification not accomplished, as it was impossible without reopening the abdomen.

Autopsy.—Fairly good walling off of site of constrictor from general peritoneal cavity. Localized infection of peritoneum beneath abdominal incision, apparently extending down to artery. Ecchymosis and constriction of artery show location of tape.

Microscopic report, kindly rendered by Dr. C. H. Rowe, is of special interest as showing probable combined effect of infection and unequal pressure upon artery by disarrangement of instrument, above referred to. It should be remembered, however, that both of these would be almost entirely eliminated in operating in man.

" Outer two-thirds of adventitia destroyed over one-fourth the circumference of artery. Beneath this area the muscularis is infiltrated with leucocytes, and nuclei of muscle cells stain poorly. Internal elastic coat nearly destroyed throughout same extent of vessel, but intima not changed. All other parts of artery are normal."

It is considerable of an indication of the relative advantage of this method over ordinary ligation that unfavorable symptoms, due to the act of closure, were not discernible, and it is especially significant that complete paralysis of the posterior extremities was not noted at any time, although Keen concludes from his experiments, which were performed four times, that "in dogs (temporary) paralysis of the hind legs follows complete obliteration of the aortic stream." These experiments are sufficient to demonstrate the fact that, at least in dogs, a large artery can be gradually constricted without undue violence to its walls. It will be impossible to approximate in lower animals the exact conditions which exist in man when the largest or atheromatous arteries are subjected to operation. However, I have in mind further investigation to note the effect of gradual and partial occlusion carried on for a period of several days longer than in the above tests. This would approximate better the procedure which might be found desirable where difficulty is met with in obtaining the establishment of the collateral circulation. Certain changes in the form of instrument also are suggested, tending to better avoid traumatism of the arterial tunics. I have, however, deemed it advisable to incorporate this preliminary report as presenting sufficiently valuable lessons.

If continued experience shall prove the feasibility of gradual occlusion, aside from its limited value in selected cases, as a preliminary to permanent ligation in the extirpation of tumors or in other operative procedures requiring complete closure or resection of large arteries, it would seem to have its most pronounced opportunity for usefulness in the relief of aneurism, through its control of the blood current. For it should be remembered that the natural and surgical cure of that disease is best brought about, not by such conditions as induce sudden clotting en masse, but rather by the gradual deposition of the coagulum within the sac. It is not suggested, however, as applicable to all cases or to displace the rightful use of present recognized methods. In few other surgical diseases are so many different procedures essential to meet the actual necessities of the individual patient, and gradual closure, as an additional resource, would seem, in a minor proportion of cases at least, to better meet existing indications than other methods. However, its relation to the cure of aneurism, together with the various modifications of technique indicated in that disease, must meet with later consideration.

It might be well to add that two things should govern the application of gradual occlusion: the artery and the condition of the heart and blood-vessels. Thus it would seem to be indicated in all patients requiring closure of the abdominal aorta,—not in this case, however, in conjunction with permanent ligation, inasmuch as the latter procedure, in man, by any means yet devised, is almost necessarily fatal. In the case of arteries of lesser caliber, except for special reasons which might determine its use for aneurism, the forcible or weak blood current, together with the presence or absence of arteriosclerosis and the accompanying lack of general tissue-vigor, would determine the desirability of adopting gradual closure or ordinary ligation.